NATIONAL STEEL AND SHIPBUILDING COMPANY

LEAPFROG TECHNOLOGY TO STANDARDIZE EQUIPMENT AND SYSTEM INSTALLATIONS

UNIVERSITY OF NEW ORLEANS SUBCONTRACT

NSRP 0537 PROJECT SP-6-95-2 Sept. 1999

SECTION NO. 2 — EQUIPMENT, SYSTEM INSTALLATION, AND TECHNICAL CRITERIA

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 1999**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **The National Shipbuilding Research Program, Leapfrog Technology to Standardize Equipment and Systems Installations, Section No.2-Equipment, System Installation, and Technical Criteria**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Surface Warfare Center CD Code 2230-Design Integration Tower Bldg 192, Room 128 9500 MacArthur Blvd Bethesda, MD 20817-5700**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**11**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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2.A CRITERIA AND REQUIREMENTS FOR EQUIPMENT INSTALLATIONS

This sub-task report provides a description of the design requirements and engineering criteria to be used in the development of the equipment installation standards.

SHIP MOTION LOADING

The strength of commercial ship foundations is typically governed by accelerations resulting from ship motions in a seaway. Ship specifications typically specify formulas for determining accelerations at different locations on the ship based on heave, surge, roll, pitch, and yaw motions. These "g" values or multiples of the weight to be supported are based solely on ship motions and equipment' location and do not vary with equipment weight or foundation stiffness.

It should be noted that a factor of safety should be used in the design of foundations limited by ship motions. This factor of safety helps ruggedize the foundation against other environmental loads such as pounding, wave slamming, and forces due to weather elements (wind, ice and snow) and helps avoid fatigue-related problems resulting from a design based purely on strength requirements. For combatants the shock induced forces generally produce the greatest load the foundations may experience, thus driving the design requirements, even then cyclic loading, fatigue and other factors may also affect the design of the foundations.

A conservative approach would be to allow the equipment installations to be loaded up to 50% of the material yield strength due to the worst ship motions. Since ship motions typically produce 2-3 times the static load, a foundation designed to this criteria would be able to support at least 4-6 times the static load. In the standards development the seaway loading or the equivalent acceleration values of 3 g's vertical, 1.5 g's transverse and 0.75 g's longitudinal are to be used, simultaneously.

ADDITIONAL LOADS

Equipment installations must be able to support attached equipment and a variety of additional loads and redistribute them into the hull structure. Weights of machinery and equipment, including liquids at operating levels and one half of the unsupported lengths of connected piping and cables, plus the dynamic effects of ship motion and vibration shall be included in the foundation assessment.

VIBRATION

Vibration issues affecting foundation systems are those resulting from hull girder excitation caused by propeller forces on the hull and from deck vibration excitations initiated by unbalanced forces in rotating machinery, structure/machinery resonance conditions or both. Reduction and/or control of structural response to the source of the excitations is essential since excessive vibration can appreciably affect the proper functioning of the supported components, can lead to damage of ship structure, machinery, equipment or systems. Vibration is also a problem when it interferes with personnel safety, comfort or proficiency. Means of preventing excessive vibration during normal ship operating conditions should be anticipated and incorporated in the design and construction of the ship. The correction of a resonance problem in a finished ship can be a very costly and time-consuming effort. There are foundation detail design requirements for vibration that evolve from the specifications and the shipbuilder's plan for implementing the requirements.

The objective of a vibration analysis is to avoid vibratory resonances. The vibratory driving frequencies normally considered include: (1) ship's blade rate, (2) ship's primary hull modes, and (3) machinery rotating speed. An equipment installation should be designed such that its natural frequencies are not in resonance with any of the driving frequencies. The action of a ship's propeller rotating in a seaway will produce periodic vertical and transverse forces directed at the ship's stern structure. These harmonic forces will excite vibration in the hull at a driving frequency of the rotating rate of the propeller times the number of blades on the propeller. Since the propeller can be rotating at any rate through a range of speeds, the practice has been to design foundations such that their natural frequencies are above the maximum blade rate (maximum shaft revolutions per minute times the number of propeller blades). This criterion need only be applied for foundations located within 1/3 of the length of the ship from the stern since hull structure will tend to dampen the harmonic driving forces and reduce the response amplitudes away from the stern. Typical ship specifications for foundations in the aft 1/3 of the ship require that the foundations and local supporting structure natural frequency should be at least 25% above blade rate. In the forward 2/3 of the ship, caution should be exercised to ensure that foundation frequencies are out of the range of the specified propeller blade operating ranges. In practice there is a low frequency that should be avoided by at least 10% and there is an upper band of frequencies close to blade rate that should be avoided. This results in a fairly wide band between the upper and lower level propeller blade rates within which foundation natural frequencies may be accommodated. However, since the propeller blade rate will pass through these frequencies as power is increased or decreased, there exists the possibility that a transitory resonant condition may exist.

The action of a ship travelling through a seaway will tend to produce harmonic motion of a ship's hull. These motions can be approximated by considering the ship's hull girder as a free-free beam with added mass included to represent the damping effect of the seawater. The resulting natural frequencies and mode shapes are referred to as ship's primary hull modes. It is these hull-driving frequencies which should be avoided in the design of foundations located within the forward part of the ship. Blade rate is usually much higher than any of the primary hull modes and as a result is critical in the aft end of the ship. However, as mentioned above, due to structural damping the blade rate criterion is not critical in the forward length of a ship and as a result the hull mode criterion takes precedence. In designing equipment installations, to avoid resonance with ship's primary hull modes, it is imperative that the mode shape of the driving frequency be considered. The direction of the driving forces for each hull mode will determine which of the foundations natural frequencies should be considered in the criterion. For example, the ship's torsional or rolling mode will have tendency to excite the transverse bending mode of a cantilevered foundation structure mounted to the deck.

The case of a foundation supporting a piece of machinery with rotating parts, which occurs often on board ship, requires an additional vibration criterion. For this situation it is also imperative that a resonance condition does not exist between the machinery's driving frequency and the natural frequencies of the foundation structure. Different criteria exist for units, which are hard mounted, and units, which are resiliently mounted. For hard mounted units it is necessary solely to avoid the machinery's rotating frequency or frequencies, however, for resiliently mounted units it is necessary that all foundation natural frequencies be a factor of 1.25 above the machinery's rotating frequency. The foundation natural frequencies for units which are resiliently mounted are determined by considering the stiffness of the foundation with associated ship's structure and considering solely the mass of the foundation and not of the unit-foundation combination. This is done due to the uncoupling effects of the resilient mounts and to ensure that there is adequate foundation stiffness and mass in way of the mounts.

In case of combatants, the mechanical vibration requirements for all machinery and equipment are typically in accordance with MIL-STD-167. The equipment, as installed, shall not have vibration interference with the operation of the ship's combat system nor degrade the accuracy or sensitivity of the ship's sensors and radar. All limitations, calculations, and analyses for vibration and balancing of electrical, hull, and machinery equipment and components are to be in compliance with MIL-STD-167.

Commercial ship foundations are often more flexible due to the lack of shock requirements. This reduced stiffness and corresponding lower frequency can increase the potential for a vibration problem. However, the situation is helped by the fact that commercial ships typically have a much lower propeller blade rate than combatants. The standards will be developed keeping in mind more of commercial applications.

NOISE

All the equipment installation design requirements for the reduction and control of structure-borne noise are based on the requirements contained in various specifications and identified in various shipbuilders overall silencing plan. The silencing plan considers the established ship noise goals; the contribution of machinery and overall equipment vibration, propeller cavitation and flow noise to the noise levels; the transmission characteristics of the resilient mounts, foundation structures and hull structure. A guide to the implementation of the specific requirements for structure-borne noise reduction and control, which affect foundation design, are generally provided in the Noise Control Program of the specific ship. For combatant ships, structure borne noise requirements are based on operational requirements to reduce and control the radiated noise signature and to decrease the ship's detection susceptibility.

Practical design implications for equipment installations are as follows:

The average stiffness of the support points in way of equipment mounts should be designed to provide a stiffness at least ten times greater than the total dynamic stiffness of the array of mounts resting on it. The dynamic stiffness values of rubber mounts are greater than the static stiffness values used in load-deflection calculations (1.2 to 1.6 x the static stiffness). From a practical standpoint 1/4" to 1/2" plate or angle thickness stiffened with small brackets in way of mount attachments are adequate to meet the dynamic stiffness requirements.

The distribution of mass in a foundation fitted with noise mounts should be such that the mass of the foundation within a periphery of 3" of the mount should be at least 1/50 to 1/100 of the mass supported by the mount.

SHOCK

This criteria is exclusively required for naval combatants only, and therefore is only briefly described for information purpose. An underwater explosion generates a shock wave of intensive pressure, which impinges against the ship hull and induces severe transient motions in the primary hull structure. These motions constitute the shock excitation environment that is transmitted through the hull to the base of the foundation system. The ideal characterization of any underwater explosion and shock excitations is the known time history of the hull shock motion at the structural interface with the foundation. Since such data are not readily available, an alternative approach of either quasi-static analysis method or Dynamic Design Analysis Method (DDAM) is used.

For combatants the shock requirements almost always govern the equipment installation design. Generally the foundations requiring shock qualifications which are not qualified by shock testing are designed for shock in accordance with "Shock Design Criteria for Surface Ships" Publication NAVSEA 0908-LP-000-3010, 1976. Shock design values used for foundation analysis are specified in the Design Data Sheet DDS-072-1 (confidential). These foundations shall be designed using appropriate shock values for location and direction using the allowable stress criteria associated with either the elastic or elasto-plastic design as indicated in NAVSEA 0908-LP-000-3010.

SWAY BRACES & LATERAL SUPPORTS

Shipboard units, which are attached to foundation structure at their base and are fairly tall in comparison to the narrow dimension of their base, pose an additional problem. These units, due to the high position of their center of gravities, will have a tendency to try to overturn about their base. As a result, regardless of the foundation stiffness, the lateral natural frequencies of the structural system will be very low. To prevent vibration excitation and excessive motions of these units it is customary to provide sway braces or any form of lateral supports at the top of the units. These added supports will eliminate the unit overturning and will raise the system lateral natural frequencies significantly, thus avoiding vibration problems.

HULL INTERFACE AND ACCESSIBILITY

Equipments are generally not supported directly on the shell or other structure exposed to wave impact, propeller excited vibrations, etc., if the resulting distortion or vibration would damage the equipment or limit its performance. Installation members that overhang supporting structure and extend onto deck or bulkhead plating should land on a pad to effect a smooth transition and to reduce the stress in the plating.

Accessibility should be provided for inspection and maintenance of the equipment installation and adjacent hull structure. Foundations should be constructed to avoid pockets, which can contain liquid.

RIGIDITY AND ALIGNMENT

Equipment installations should be rigid enough to ensure that the requirements for limiting twist, bend, level and parallelism with the master datum as specified by equipment manufacturers are met. The rigidity of foundations and supporting structure should be sufficient to prevent misalignment, which would interfere with operation of the machinery and equipment, and to preclude excessive vibratory motion.

Equipment installations should be designed to prevent misalignment or excessive strains due to thermal expansion under all operating conditions.

FATIGUE

Equipment installations subjected to cyclically repeated or reversed loadings should be designed to withstand fatigue. Appropriate rules of classification societies should be consulted to design for fatigue.

CORROSION CONTROL AND PROTECTION

Equipment installations protection and corrosion control requirements should be met during the construction and service life of the ship. Appropriate measures should be taken during the design of foundations to provide access for maintenance and to avoid the effects of corrosion. Treatment of foundations in way of wet and dry spaces, machined surfaces, dissimilar metals, and void spaces must be incorporated in the fabrication and installation process in the proper sequence to achieve preservation and corrosion protection in the most cost effective manner.

ALLOWABLE STRESSES

Under the normal design loads, stresses in steel should not exceed the following allowable limits. These limits are based on allowable criteria generally used for commercial ships; the limits can vary depending on the specifications of specific ships.

Tensile and bending stresses - where there is no danger of failing from instability, allowable limits for the algebraic sums of axial and bending stresses are 50% of material yield strength, as listed in Table 1.

Shear Stresses - where there is no danger from instability, allowable limits for shear stresses are 75 percent of the allowable tensile and bending stress.

For both Elastic and Elastic/Plastic design, the tensile stress in an axially loaded member shall not exceed the material static yield strength.

MATERIAL	NOM. YIELD STRENGTH (KSI)[1]	ELASTIC ALLOWS. STRESS (KSI)	ELASTIC SHEAR STRESS (KSI)	ELASTIC /PLASTIC BENDING STRESS (KSI)[2]	ELASTIC /PLASTIC SHEAR STRESS (KSI)
STEEL					
ORDINARY STRENGTH (OS)	34	17	13	34	26
HIGHER STRENGTH (HS)	51	26	19	51	38
HIGH YIELD (HY-80)	80	40	30	80	60

NOTES: 1) YIELD STRENGTHS FOR STEEL SHALL BE OBTAINED FROM APPLICABLE MATERIAL SPECIFICATIONS.
2) 100% OF NOMINAL YIELD STRENGTH.

Table 1 — Allowable Limits for Foundation Structural Members

Threaded fasteners and hold down bolts requirements for components shall be as defined in the applicable component specification. In case of stud fabricated foundations and stud mounted equipment's the stud allowable stress in bending can be 60% and in shear 45% of its material yield strength, respectively.

The limiting frequency as discussed before should be 1.25 times the maximum propeller blade rate.

2.B CRITERIA AND REQUIREMENTS FOR DISTRIBUTIVE SYSTEM INSTALLATIONS

This sub-task report provides a description of the design requirements and engineering criteria to be used in the development of the distributive systems installation standards.

The criteria and requirements can be categorized into two groups, namely, Global criteria which are applicable to all types of installations, and Specific criteria & requirements applicable to the specific installation type.

Under the **Global** criteria the following requirements are evaluated:

SHIP MOTION LOADING

The strength of commercial ship installations is typically governed by accelerations resulting from ship motions in a seaway. Ship specifications typically specify formulas for determining accelerations at different locations on the ship based on heave, surge, roll, pitch, and yaw motions. These "g" values or multiples of the weight to be supported are based solely on ship motions and systems location and do not vary with system structure weight or installation stiffness.

It should be noted that a factor of safety should be used in the design of installations limited by ship motions. This factor of safety helps ruggedize the installation against other environmental loads such as pounding, wave slamming, and forces due to weather elements (wind, ice and snow) and helps avoid fatigue-related problems resulting from a design based purely on strength requirements.

A conservative approach would be to allow the system installations to be loaded up to 50% of the material yield strength due to the worst ship motions. Since ship motions typically produce 2-3 times the static load, an installation designed to these criteria would be able to support at least 4-6 times the static load. In the standards development the seaway loading or the equivalent acceleration values of 3 g's vertical, 1.5 g's transverse and 0.75 g's longitudinal are to be used, simultaneously.

ADDITIONAL LOADS

System installations must be able to support the attached distributive system and a variety of additional loads and redistribute them into the hull structure. Weights of valves, fittings and connections, including liquids and one half of the unsupported lengths of connected piping and cables, plus the dynamic effects of ship motion and vibration shall be included in the installation assessment.

VIBRATION

Vibration issues affecting installation systems are those resulting from hull girder excitation caused by propeller forces on the hull and from deck vibration excitations initiated by unbalanced forces in rotating machinery, structure/machinery resonance conditions or both. Reduction and/or control of structural response to the source of the excitations is essential since excessive vibration can appreciably affect the proper functioning of the supported components, can lead to damage of ship structure, machinery, equipment or systems. Vibration is also a problem when it interferes with personnel safety, comfort or proficiency. Means of preventing excessive vibration during normal ship operating conditions should be anticipated and incorporated in the design and construction of the ship. The correction of a resonance problem in a finished ship can be a very costly and time-consuming effort. There are installation detail design requirements for vibration that evolve from the specifications and the shipbuilder's plan for implementing the requirements.

Typical ship specifications for installations in the aft 1/3 of the ship require that the installations and local supporting structure natural frequency should be at least 25% above propeller blade rate. In the forward 2/3 of the ship, caution should be exercised to ensure that installation frequencies are out of the range of the specified propeller blade operating ranges. In practice there is a low frequency that should be avoided by at least 10% and there is an upper band of frequencies close to blade rate that should be avoided. This results in a fairly wide band between the upper and lower level propeller blade rates within which installation natural frequencies may be accommodated.

Commercial ship installations are often more flexible due to the lack of shock requirements. This reduced stiffness and corresponding lower frequency can increase the potential for a vibration problem. However, the situation is helped by the fact that commercial ships typically have a much lower propeller blade rate than combatants. The standards will be developed keeping in mind more of the commercial applications.

NOISE

All the system installation design requirements for the reduction and control of structure-borne noise are based on the requirements contained in various specifications and identified in various shipbuilders overall silencing plan. The silencing plan considers the established ship noise goals; the contribution of machinery and overall equipment vibration, propeller cavitation and flow noise to the noise levels; the transmission characteristics of the resilient mounts, system installation structures and hull structure. A guide to the implementation of the specific requirements for structure-borne noise reduction and control, which affect installation design, are generally provided in the Noise Control Program of the specific ship.

LAYOUT AND SPACING

System layout order and sequence should be established, to allow accurate and efficient installation in a timely and cost-effective manner. Installation spacing is another indirect governing criteria, controlling the weight per installation and thereby controlling the installation members sizing.

HULL INTERFACE AND ACCESSIBILITY

Installation members that overhang supporting structure and extend onto deck or bulkhead plating should land on a pad to effect a smooth transition and to reduce the stress in the plating. The installation attachments to the ship structure should be such that they accomplish a smooth transfer of loads and minimize stress concentrations. Mechanical fastening methods and other alternative attachment techniques should be evaluated.

Accessibility should be provided for inspection and maintenance of the installations, attachments and adjacent hull structure. Installations should be constructed to avoid pockets, which can contain liquid.

FATIGUE

System installations subjected to cyclically repeated or reversed loadings should be designed to withstand fatigue. Appropriate rules of classification societies should be consulted to design for fatigue.

CORROSION CONTROL AND PROTECTION

System installations protection and corrosion control requirements should be met during the construction and service life of the ship. Appropriate measures should be taken during the design of installations to provide access for maintenance and to avoid the effects of corrosion. Treatment of installations in way of wet and dry spaces, machined surfaces, dissimilar metals, and void spaces must be incorporated in the fabrication and installation process in the proper sequence to achieve preservation and corrosion protection in the most cost effective manner.

FASTENING AND WELDING

Fasteners used, as part of the installation should be evaluated for adequacy. Standard mechanical COTS fasteners should be used wherever possible. Welding should comply with ship general specifications or the shipyard welding standards and standard welding details.

ALLOWABLE STRESSES

Under the normal design loads, stresses in steel should not exceed the following allowable limits. These limits are based on allowable criteria generally used for commercial ships; the limits can vary depending on the specifications of specific ships.

Tensile and bending stresses - where there is no danger of failing from instability, allowable limits for the algebraic sums of axial and bending stresses are 50% of material yield strength, as listed in Table 1.

Shear Stresses - where there is no danger from instability, allowable limits for shear stresses are 75 percent of the allowable tensile & bending stress.

For both Elastic and Elastic/Plastic design, the tensile stress in an axially loaded member shall not exceed the material static yield strength.

MATERIAL	NOM. YIELD STRENGTH (KSI)[1]	ELASTIC ALLOW. STRESS (KSI)	ELASTIC SHEAR STRESS (KSI)	ELASTIC /PLASTIC BENDING STRESS (KSI)[2]	ELASTIC /PLASTIC SHEAR STRESS (KSI)
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NOTES: 1) YIELD STRENGTHS FOR STEEL SHALL BE OBTAINED FROM APPLICABLE MATERIAL SPECIFICATIONS.
2) 100% OF NOMINAL YIELD STRENGTH.

Table 2 — Allowable Limits for Foundation Structural Members

Threaded fasteners and hold down bolt requirements for certain standard components and fittings on the distributive systems should be defined in the applicable component specification. In case of stud fabricated installations and stud mounted system runs, the stud allowable stress in bending can be 60% and in shear 45% of its material yield strength, respectively.

The limiting frequency as discussed before should be 1.25 times the maximum propeller blade rate.

Under the **Specific** criteria, three major ship-system types, namely, Piping, Electrical/Wireways, and Ventilation/Ducting, categorized the system installations. A fourth category was also established, not based on ship-system, but based on ship-structure interface. This category is installations on Joiner Bulkheads. Specific installation types further elaborated the specific criteria and requirements under each of these major ship-system groups.